Chapter 3:
Biofuel Feedstocks—Energy Crops, Biomass, and Waste Products

While Massachusetts will never be a source for fossil fuel extraction or production, it does have potential to provide feedstocks for the production of advanced biofuels. Developing the infrastructure, markets and production facilities to use local agricultural feedstocks (such as switchgrass), sustainable forestry feedstocks, agricultural waste (such as cranberry waste), and other waste streams (such as paper sludge, sawmill waste, etc.) has the potential for economic development in the agriculture, R&D, and manufacturing sectors. In addition, such development would provide both greenhouse gas reduction and fuel security benefits.

This chapter presents an overview of the feedstocks within Massachusetts that are available to support production of biofuels. These feedstocks are generally woody cellulosic materials and waste materials, for example, derived from the organic component of municipal solid waste (MSW), that can be used to produce ethanol, and waste oils and greases that are source material for biodiesel and other liquid biofuels. The table below provides a summary of the potential supplies of these feedstocks, which are described more fully in the subsequent sections.

The potential production of cellulosic ethanol, from the feedstocks within the state, totals to about 156 million gallons a year, which is 6% of the 2.67 billion gallons per year of gasoline that the state consumed in 2006. Importantly, this same feedstock is also under consideration by state policymakers and developers for renewable

Table 3.1. Sustainable Annual Potential Massachusetts Feedstocks and Biofuel Production[1]

Source	Supply		Energy	Biofuel Production* (million gallons)	
	Green Tons	Dry Tons	Trillion BTUs	Ethanol	Biodiesel
Energy Crops (cellulosic)					
Farmland (20% substitution)	201,000	163,000	2.8	13.0	
Idle Farmland	179,000	145,000	2.5	11.6	
Woody Residues and Forest Biomass					
Western Massachusetts (5 counties)	1,256,000	657,000	11.3	52.6	
Surrounding Counties from bordering states	9,300,000	4,866,000	83.7	389.3	
Waste Products					
Organic Components of MSW**	1,862,000	980,000	16.9	78.4	
Restaurant Waste Oils/Grease	29,000				6.4
Wastewater Grease	42,000				1.5

* Assumes conversion of 80 gallons of ethanol per dry ton biomass; and 80% and 10% conversion efficiencies for restaurant and wastewater production of biodiesel, respectively.

** Calculated as organic component of MSW waste-stream that currently goes to landfills, plus 50% of volume that currently goes to trash-to-energy facilities, minus 50% of the paper volume, which is assumed diverted to recycling at higher rates than at present.

energy power and thermal applications. Additional feedstocks from agricultural wastes, such as those generated by cranberry processing, have not been included. Use of such wastes for biofuel may become valuable for the state's agriculture sector, providing a new revenue stream for growers, and should be encouraged by state policy. But these wastes are unlikely to make a substantial contribution to the overall feedstock volume available for conversion to biofuels.

Energy Crops in National and Regional Context

The term "energy crop" refers to plants grown specifically as feedstock for energy production—either for fuel for heating and power plants, or for processing into biofuels. Since energy crops are typically cultivated on agricultural lands that might otherwise grow food, direct and indirect impacts on land use and the environment must be considered (see Chapter 2). Corn and soybeans are the dominant energy crops grown in the U.S. for ethanol and biodiesel production, respectively. In the Northeast, recent attention has focused on switchgrass and willow (salix) as cellulosic energy crops for heat and power.

The U.S. Departments of Energy and Agriculture have supported programs to study and demonstrate energy crops—particularly switchgrass, willow, and hybrid poplar. Oak Ridge National Laboratory in Tennessee hosts the Bioenergy Feedstock Information Network[2] and offers a model to assess the economic opportunities for energy crops on a state-by-state level.

Regionally, New York State has a lead role in the commercialization of willow, under the leadership of the State University of New York's College of Environmental Science and Forestry in Syracuse.[3] Several hundred acres of commercial willow plantations in New York are providing biomass fuel for co-firing in coal power plants, and the state also has an intensive bioenergy research agenda.

In Vermont, the state university is engaged in a one-year pilot project to assess the potential for production and processing of oil-seed and sugar-containing crops for use as a renewable energy source on a scale suitable for local farmers.[4] Site trials have been performed on two farms in Shaftsbury, VT, and initial findings suggest that canola and sunflower have the best potential as oil-producing crops for the Vermont region.

The Connecticut Agricultural Experiment Station[5] has also investigated canola and soybeans, while the University of New Hampshire Cooperative Extension[6] has experimented with a number of sunflower varieties.

Energy Crops in Massachusetts

In comparison with other states, Massachusetts is not a large agricultural producer. Nonetheless, prospects for growing energy crops in the Bay State are of interest because of the potential benefits derived from diversifying our agricultural sector, keeping marginal or threatened agricultural lands in production and of providing income from open lands not currently in agricultural production.

Several important developments—centered largely on efforts at the UMass-Amherst—have recently increased understanding of the potential for energy crops in Massachusetts.

Switchgrass Site Trials: In 2006, 12 varieties of switchgrass were planted by the UMass Plant and Soil Science Department at the South Deerfield agricultural experimentation station. Based on productivity studies over the 2007 growing season, significant differences were determined among the varieties, and several were identified as worthy of further investigation. The site trial is located in some of the best agricultural soils in the Commonwealth, so further evaluation is needed in a range of soil conditions where energy crops might have economic potential.

Energy Crop Potential Study: As part of the Massachusetts Sustainable Forest Bioenergy Initiative led by the state Division of Energy Resources and Department of Conservation and Recreation, the UMass Department of Resource Economics completed a preliminary study in January 2008 of the potential for energy crops in the Commonwealth.[7] The study examined switchgrass and willows based on cost and productivity data from Oak Ridge National Laboratory and the UMass site trials, compared energy crop costs with costs of woody biomass fuel from residues and forestry, and analyzed the acreage of lands potentially available for energy crop production. The results of this study are provided later in this chapter.

Crambe Research and Development: *Crambe abyssinica*, an Abyssinian mustard, is an industrial oil crop that has enormous potential as a low input source of renewable cellulosic biomass for bioenergy and biodiesel production. Crambe is an ideal biodiesel feedstock, with seed oil content of 40% to 50%. Native to the Mediterranean region, crambe is a non-food, cool season, non-invasive crop that has been domesticated and grown commercially in the U.S.—particularly in colder regions—since 1990. Following initial commercial production in North Dakota with support of the U.S. Department of Agriculture, U.S. cultivation of crambe peaked in 1993 at nearly 60,000 acres, but diminished after the federal support was ended.

In addition to its high seed oil content, crambe is well suited for biodiesel due to the high level of erucic acid (60%-67%) in its seed oil. Erucic acid is a heat stable, long chain fatty acid that is a critical raw material of industry as an additive to lubricants and solvents, plasticizers, high temperature hydraulic fluids, pharmaceuticals, cosmetics, and other products. Crambe has also been used for remediation of sites contaminated with toxic metals and is productive in marginal soil conditions.

Dr. Om Parkash, an Assistant Professor in the Department of Plant, Soil, and Insect Sciences at UMass-Amherst, is a leading national researcher on crambe who has developed the genetic transformation system for the plant enabling genetic modifications to enhance the plant's ability to produce oil and grow in marginal lands.[8]

The Institute for Massachusetts Biofuels Research: The Institute for Massachusetts Biofuels Research (TIMBR) is a multi-disciplinary research consortium at UMass dedicated to increasing the use of biomass for energy and fuel. Through a recent National Science Foundation award, Institute researchers in chemical engineering are engaged in refining a range of feedstocks into biofuels: biodiesel, bio oil, methanol, cellulosic ethanol, and others.

> The potential production of cellulosic ethanol from feedstocks within the state totals about 156 million gallons a year, which is 6% of the 2.7 billion gallons of gasoline that the state consumed in 2006.

Potential for Energy Crops in Massachusetts

The University of Massachusetts Department of Resource Economics recently completed a study[9] evaluating the potential for biomass energy crops in the Commonwealth. Performed as part of the Massachusetts Sustainable Forest Bioenergy Initiative,[10] the study was limited in its scope, focusing on willow and switchgrass potential in the five westernmost counties. It analyzed expected crop production prices and considered three sources of land for growing energy crops: replacing crops on existing farmland with energy crops; planting energy crops on idle farmland; and converting forested land to energy crops.

Both switchgrass and willow can grow in Massachusetts with yields expected to be four to five times as great as biomass yields from forestlands (40-55 million BTU per acre for switchgrass and willow compared with 10 million BTU per acre for forests).

The study revealed that the cost of producing energy crops is difficult to determine. Nevertheless, existing models were used to establish cost estimates. The results suggest that energy crops are reasonably close to competitiveness with forest-derived wood chips. For delivered fuel to a biomass energy plant, cost for willow and switchgrass was determined to be $32 per ton and $68 per ton, respectively, compared with $31 per ton for forest-derived wood chips. Taking into account the difference in moisture content, the findings suggest costs of $3.69 per million BTU and $4.94 per million BTU for willow and switchgrass, respectively, compared with $3.32 per million BTU for forest-derived wood chips. Processing switchgrass into fuel pellets requires additional costs but provides a premium fuel product that would compete with wood pellets. This study notes the speculative nature of the price estimate for the energy crops, and the sensitivity of these prices to soil conditions, cultivation and harvesting operations and further progress on crop yields.

The UMass researchers also looked at potential lands that could be devoted to growing energy crops and the total energy contribution that could be realized. Considering the current land in active agriculture in the five westernmost counties, if 20% (67,000 acres) were converted to energy crop production, an estimated 2.8 trillion BTUs of energy could be supplied. This energy represents 5.3% of the potential demand for biomass fuel, as calculated by the researchers to supply energy for residential and commercial heating and an expected build-out of 165 MW of biomass electric power. If all idle farmland (60,000 acres) were put into production of energy crops, an additional energy yield of 2.5 trillion BTUs could be realized, representing 4.7% of the potential demand for biomass.

Researchers did not consider the use of marginal and open lands not in agriculture, but those lands could also provide significant production. The integration of energy crops into the state's Agricultural Preservation Restriction program could be useful to maintain open space and working landscapes on qualifying lands where available labor and economics call for lower intensity farming activity.

Energy crops generally require less intensive cultivation than conventional crops, especially after a plantation is first established. As energy crop research and development progresses in Massachusetts, water demand and pesticide use should be carefully evaluated.

Algal Biofuels

High lipid algae—the subject of federal research from 1978 to 1996—is a promising source for future production of biodiesel and other biofuels.[11] Depending on the species, algae contain 20% to 40% lipids by weight. Lipids are oils that make these algae well suited for conversion into biodiesel. Algae also have high growth rates and can be harvested daily, giving them an advantage over conventional sources of biodiesel such as soybeans, which are harvested annually. Algae also have a much higher yield per acre than conventional biodiesel sources, producing between 5,000 and 20,000 gallons per acre per year. The source with the next greatest yield, oil palm, only produces 635 gallons per acre per year. Moreover, algae do not require soil for growth and can be located on non-agricultural land, thereby avoiding some of the direct and indirect land use impacts associated with other biofuel sources.

The extraction of oil from algae for conversion into liquid biofuels is already well documented. Liquid biofuels such as biodiesel produced from algae is sulfur- and toxin-free, and highly biodegradable. In addition, the use of carbon dioxide emissions from power plants to grow algae is now being championed by a number of start-up companies, notably GreenFuel Technologies Corp. of Cambridge.[12]

Despite these advantages, a number of technological and engineering challenges must be overcome before algae-based biofuels can become a commercially viable alternative to conventional diesel or heating oil. The cultivation of algae can only occur under specific light, temperature, and density conditions. Waste oxygen created in the growth process must be continually removed. In addition, open algal ponds are subject to evaporation and rainfall that can create salinity and pH imbalances and local species of algae can overgrow the desired strain.[13] It will also be necessary to more fully understand the molecular biology of algae and the manipulation of molecular switches that cause increases in oil production in order to commercialize algae biodiesel. As a center for biotechnology research and business, Massachusetts is well positioned to develop and benefit from this technology.

Woody Biomass from Residues and Forests

Woody biomass is a substantial cellulosic feedstock in Massachusetts that can be used for local production of cellulosic ethanol once that technology becomes available. Woody biomass comes either from residues from current economic activities or from sustainable forest management. Residues include wood wastes from forest products industries, trees removed for land development, tree trimmings from parks and utility line maintenance, and a large fraction of construction and demolition debris. In Massachusetts, forest biomass resources come from active forest management, which must conform to strict sustainable forestry regulations established under the Massachusetts Forest Cutting Practices Act. This forest management should be consistent with sustainability certification provided by the Forestry Stewardship Council and provide timber harvesting that enhances the forests' ecological and economic value.

The Commonwealth's Division of Energy Resources and the Department of Conservation and Recreation are engaged in the Massachusetts Sustainable Forest Bioenergy Initiative which has assessed the woody biomass resource potential and economic impact of a biomass energy economy. The Initiative will establish a strategic plan for developing the supply chain infrastructure needed to bring this fuel to the market.

The woody biomass resource assessment[14] is focused on the five western counties of Massachusetts, as well as surrounding counties in bordering states. The assessment determined that the sustainable supply of woody biomass from residue sources is roughly 630,000 green (inclusive of water content) tons per year, and capable of expanding to 3.6 million tons per year inclusive of the surrounding states.

The Sustainable Forest Bioenergy Initiative is primarily focused on biomass for electric power and thermal energy. The potential translates into 100 MW of sustainable electric generation capacity from Massachusetts-based resources, expanding to nearly 700 MW inclusive of the supplies from the surrounding counties of bordering states.

The availability of woody biomass for conversion to liquid biofuels will depend on the competitive ability to pay for fuel in the electric, thermal, and fuel markets. The current price for delivered wood chips to biomass energy plants is $25-$35 per green ton.

> A biofuels industry would have significant impact on the rural Massachusetts economy, benefiting 500 licensed foresters, 60 sawmills, thousands of secondary manufacturers, and numerous landowners. The industry would also provide high paying jobs to rural Massachusetts workers including plant operators, technicians, and engineers.
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> *—A Report of the UMass Clean Energy Working Group, February 2008*

Developing the infrastructure, markets and production facilities to use local agricultural feedstocks (such as switchgrass), sustainable forestry feedstocks, agricultural waste (such as cranberry waste), and other waste streams (such as paper sludge, sawmill waste, etc.) has the potential for economic development in agriculture, R&D, and manufacturing. In addition, such development would provide both greenhouse gas reduction and fuel security benefits.

Biofuels from Organic Waste Feedstocks

Waste organic products can also be used as feedstocks for the production of biofuels. With processing, wastes that are high in oil content can meet standard specifications for commercial fuels such as heating oil and transportation diesel. The potential supply is limited, but using these feedstocks is likely to yield substantial greenhouse gas reductions and may offer an environmentally superior method of disposing of these wastes. One study found that "biodiesel and bioethanol routes are generally energy intensive…[but] in the case of biodiesel from waste vegetable oil, the energy balance is more favorable, with the energy in the biodiesel estimated at between 6.6 and 8 times that of the non-renewable energy input."[15] Another study found similarly positive results for use of waste animal fats.[16]

A greater variety and volume of wastes, including the organic components of municipal solid waste, can potentially be used as feedstock for cellulosic fuel, although the technologies for converting them are currently in development. Great care must be exercised to ensure that the ultimate waste byproducts of the fuel production process are disposed of properly. In particular, the potential use of waste material, including construction and demolition debris, organic components of municipal solid waste, sewage sludge, etc. in the production of biofuels raises concerns over releases of heavy metals and other contaminants. More information is needed to understand and evaluate the potential effect on human health and the environment of such uses.

Appropriate waste products include:

- Vegetable oils and animal fats from restaurants and commercial food processing facilities,
- Sludge or grease derived from wastewater and the treatment of wastewater,
- Animal byproducts, including poultry fats and meat processing wastes,
- Agricultural wastes, including residues from cranberry processing, and livestock waste, and
- Organic components of municipal solid waste, including mixed paper, food waste, and yard waste.

The processing of waste into biodiesel that meets American Society for Testing and Materials (ASTM) standards (necessary for use in automobile engines or home heating systems) requires considerable sophistication and rigorous testing to ensure quality control. Although not yet ASTM-certified fuels, other biofuels that can compete with petroleum for use in generating heat or power are produced by several companies.

Waste vegetable oil and animal fats are feedstocks used by the only company in Massachusetts that currently produces biodiesel in significant volume, MBP Bioenergy. This Massachusetts biodiesel plant illustrates that while biofuels are easier to produce from virgin vegetable oils, waste feedstock has important economic advantages, and avoids many of the negative environmental impacts that result from the disposal of waste oils and the use of virgin feedstocks.

The U.S. Department of Energy estimates that the restaurant industry generates a volume of waste oil equal to nine pounds per person annually.[17] Based on this figure and our state's population, approximately 6.4 million gallons of biodiesel could be made in Massachusetts annually if this waste were processed into this biofuel. Collection, however, poses problems. Small volumes are generated at many distributed locations, requiring waste to be collected in "milk runs" that increase costs and reduce the greenhouse gas benefits of the resulting fuel.

The same U.S. Department of Energy report estimates that the nation's wastewater contains about 13 pounds of grease per person annually. In Massachusetts, this figure implies that approximately 1.5 million gallons of biodiesel per year could be produced from this waste, but once again, collecting it results in costs for transportation and pretreatment, which may reduce potential environmental and economic benefits. Municipalities require restaurants to pump out grease traps regularly, but if this clean-out does not occur or if facilities have not installed a grease trap, wastes are discharged directly into municipal sewer systems not designed to treat them. Grease trap waste is a contributor to sewer system overflows,[18] creating expensive clean-up problems.

Much larger volumes of organic waste are potentially available from municipal solid waste (MSW) for conversion into cellulosic fuel. Use of the organic portion of MSW could also help address waste disposal problems, after waste streams have been minimized through reuse and recycling wherever feasible. Proactive steps should be taken to prevent a strong market for the use of organic MSW components as feedstock from acting as a disincentive to recycling and reuse.

Solid waste can be processed into biogas, and then liquid biofuels, through gasification, fermentation, pyrolysis, and anaerobic digestion. There are numerous challenges to creating usable biofuels including issues related to the high level of contaminants and water in the feedstock.[19]

As of 2006, approximately 3.5 million tons of MSW were sent to landfills (both in- and out-of-state) or combustion facilities, after large portions of the waste stream were diverted to recycling and composting. At present, much of the waste goes to combustion facilities under long-term contracts, but these contracts will expire over time and full development of the cellulosic industry is not assumed to occur until 2025 (see Chapter 1). In addition, it is hoped that an increased fraction of the paper waste can be recycled, through improved recycling programs. For purposes of estimating the feedstock available for cellulosic fuel, we have assumed that all the organic material currently going to landfills, plus half of that going to combustion facilities, will be available. From that combined total we then subtract half of the paper waste, assuming that it goes to recycling. The remainder is approximately 1.9 million tons of wet or "green" material, yielding 980,000 dry tons.[20]

Policy Recommendations:

Note: A variety of tax and other state incentives have the potential to support the development of advanced biofuel feedstocks in the Commonwealth. Recommendations relating to this are discussed in detail in Chapter 6.

1. Conduct additional field trials and commercial demonstrations of biomass crops in Massachusetts to determine optimal crops, production methods, and costs for the state. Trials on marginal agricultural land and other working landscapes are of particular interest. Evaluation of these trials should include environmental impacts (including carbon emissions and soil sequestration) and infrastructure needs for planting, harvesting, and transporting materials.
2. Expand the preliminary UMass study on economic potential of energy crops in Massachusetts to include other crops and non-agricultural marginal lands and to improve yield and cost assumptions. Develop a spatial model illustrating potential lands that may be conducive to biomass crops.
3. Support development work (genomic and breeding) on energy crops such as crambe and switchgrass to improve crop yields and biofuel production.

Crambe abyssinica, an Abyssinian mustard, is an industrial oil crop that has enormous potential as a low input source of renewable cellulosic biomass for bioenergy and biodiesel production.

4. Explore opportunities to promote algae production by the Massachusetts aquaculture industry and bioengineering research at Massachusetts companies and universities.

5. Conduct an internal review of all state agricultural preservation and assistance programs for the purpose of integrating energy crop production into the programs. Explore the benefit of establishing capacity at the state Department of Agricultural Resources and UMass Extension to provide outreach and training to farmers and other landowners interested in establishing early commercial plantations.

6. Complete the current work of the Massachusetts Sustainable Forest Bioenergy Initiative on woody residue and forest biomass feedstock and consider in its strategic plan the potential use of this feedstock for production of cellulosic ethanol.

7. Encourage and work with the federal government to support biorefinery technologies and demonstration projects that can be developed on smaller scales to utilize locally available fuel, including waste feedstocks.

8. Investigate the feasibility and design of a statewide program to collect and transport waste vegetable oil and grease trap waste to biofuel production facilities from Massachusetts restaurants and institutional kitchens. The investigation should consider the needs of the existing infrastructure for collection, transportation and processing these wastes, and the use of technical assistance, incentives and mandates to accomplish these goals.

9. Due to the inherent environmental benefits of reusing waste products over virgin sources of biofuels, give state environmental agencies the authority to reduce or provide exemptions from greenhouse gas emissions lifecycle analysis requirements when applied to biofuels produced from waste feedstocks.

10. Further investigate the applicability of cellulosic waste materials including the organic fractions of municipal solid waste, paper sludge, and construction and demolition debris for cellulosic ethanol production, while maintaining strict regulatory controls to ensure that no increases in toxics or other pollutants takes place.

Chapter 3 Endnotes

1. Feedstock data from Mass. Division of Energy Resources. Sources for volumes of solid waste: "Waste Reduction Program Assessment and Analysis for Massachusetts," Tellus Institute for the Massachusetts Dept. of Environmental Protection, February 2003; "2006 Solid Waste Date Update on the 'Beyond 2000 Solid Waste Master Plan'," Mass. Dept. of Environmental Protection, Feb. 2008. Calculations by DEP and Task Force staff.

2. http://bioenergy.ornl.gov/

3. http://www.esf.edu/willow/

4. http://www.uvm.edu/~susagctr/SAC%20Oilseed%20Report_Final.090107.pdf

5. http://www.ct.gov/caes/

6. http://extension.unh.edu/

7. Timmons, D., Allen, G., and Damery, D., "Biomass Energy Crops: Massachusetts' Potential", January 2008, http://www.mass.gov/doer/programs/renew/bio-ma-potential-crop.pdf.

8. http://www.bio.umass.edu/plantbio/faculty/parkash.html

9. See endnote 7.

10. http://www.mass.gov/doer/programs/renew/bio-initiative.htm

11. "Biodiesel from Algae Oil", Mora Associates, research report, July 2007, http://www.moraassociates.com/content/publications/0707%20Biodiesel%20from%20algae%20oil.pdf.

12. http://www.greenfuelonline.com/

13. Bullis, K., "Algae-Based Fuels Set to Bloom", Technology Review, February 5, 2007, http://www.technologyreview.com/Energy/18138/.

14. Innovative Natural Resource Solutions LLC, "Biomass Availability Analysis—Five Counties of Western Massachusetts", January 2007, http://www.mass.gov/doer/programs/renew/bio022808-wmass-assess.pdf.

15 "Technology Status Review and Carbon Abatement Potential of Renewable Transport Fuels in the UK," J. Woods and A. Bauen, Centre for Energy Policy and Technology, Imperial College London, on behalf of the UK Dept. of Trade and Industry, 2003, page iv.

16. Froling, et. al., Hydrothermal Processing in Biorefinery—A Case Study of the Environmental Performance, 7th World Congress of Chemical Engineering, July 2005.

17. "Urban Waste Grease Resources Assessment", National Renewable Energy Laboratory, Appel Consultants, November 1998 (NREL/SR-570-26141)

18. "Report to Congress on the Impacts and Control of CSOs and SSOs", U.S. EPA, 2002

19. "Sustainable Biofuels: Prospects and Challenges, The Royal Society", Policy Document, January 2008.

20. Data sources for solid waste volumes: "Waste Reduction Program Assessment and Analysis for Massachusetts," Tellus Institute for the Massachusetts Dept. of Environmental Protection, February 2003; "2006 Solid Waste Date Update on the 'Beyond 2000 Solid Waste Master Plan'," Mass. Dept. of Environmental Protection, Feb. 2008. Calculations by DEP and Task Force staff.